PVEX - AN EXPERT SYSTEM FOR PRODUCIBILITY/VALUE ENGINEERING

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ABSTRACT. This paper describes PVEX, an expert system that solves the problem of selection of the material and process in missile manufacturing. The producibility and value problem has been deeply investigated in the past years, and was written in dBase III and PROLOG before. This project represents a new approach to it in that the solution is achieved by introducing hypothetical reasoning, heruistic criteria integrated with a simple hypertext system and shell programming. PVEX combines KMS with Unix scripts which graphically depicts decision trees. The decision trees convey high level qualitative problem solving knowledge to users, and a stand-alone help facility and technical documentation is available through KMS. The system the authors developed is considerably less development costs than any other comparable expert system.

INTRODUCTION

The selection of the material from which the structure to be made, and the selection of the process by which the shape of the structure is assembled are two major steps in missile manufacturing. The procedures by which the material and the process are determined are to a great part a function of the experience of the design and manufacturing engineer, of the performance requirements for the final product and of the cost of the material and the process. For sophisticated missile systems, these procedures are interrelated and difficult to separate, particularly where the engineer's experience is concerned. Accordingly, some means is needed for capturing the knowledge and experience of the design and manufacturing engineer at the onset of the design of the structure and the manufacturing processes. If this means were properly defined, it could also be used to "reverse" engineer structures already designed, and then in turn determine more cost effective ways of producing these structures. The state-of-the-art in expert systems provides the essential elements for developing such a capability. This paper describes the steps taken to develop such a system, the Producibility/Value Engineering Expert System (PVEX), from a rudimentary prototype written originally in dBASE III.

PVEX, as it has evolved over its development, links a computer-aided design system and a very powerful database management system together to form a highly "intelligent" design tool useful both for initial design and for "reverse" design of metal structures for missile systems. It also has the necessary interface provisions for being incorporated into an automated computer integrated manufacturing (CIM) system, which is the logical extension for the system. The system is hosted by a Sun Microsystems 3/60 workstation.

REQUIREMENTS

Compatible with both the Sun 3/60 workstation and CADDS was the basic requirement for developing PVEX, which meant that PVEX must be also UNIX based. Since so much of the

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design knowledge consisted of materials and process databases, capable of accessing these databases was the second requirement for PVEX. Because of the practical difficulties in creating an all-inclusive database, a subsidiary requirement was identified that PVEX be able to access both its own and external databases. Thus, if some seldom used material were to be considered, PVEX could access an appropriate database through a telecommunications line when necessary. The third requirement for developing PVEX was that the system must provide the means for handling materials and process selection heuristics; that is, the procedures and logic by which the material and forming/shaping processes are selected by the design engineers.

These three major requirements imply several subordinate requirements, including finding appropriate software tools, selection of the development process, development of the materials selection and process selection heuristics, and coding and validation of the system. The most crucial of these requirements was the development of the material and process selection heuristics, as this is one of the least well documented aspects of the design process. Further, this is a process that is heavily dependent upon the experience of the designer, so this in effect forced the requirement that the PVEX system be capable of capturing this experience as it would be used by the designer.

There were several other requirements identified for the system, in part as a consequence of good software practice and in part as a demand that the user be able to use the system without extensive training. Thus, the system is highly interactive, with an abundance of help facilities. To a great extent, the software used is self-documenting, so that the code itself serves as its own documentation. Finally, it seemed reasonable that the system be easily transportable to other UNIX systems with little or no modification.

DEVELOPMENT TOOL SELECTION

The rudimentary version of PVEX was written in dBASE III, which proved to be inadequate for the intended use. A subsequent version was written in PROLOG, but it too was inadequate. It was evident that the selection of the language and development tool required for the PVEX should be investigated in depth. Accordingly, there were five tools that were considered in some detail. These were:

- Automated Reasoning Tool (ART)
- CLIPS
- Knowledge Pro
- Knowledge Management System (KMS)
- Nexpert *Object*

The procedure was to set up prototypes with each of these tools and then select the best one. As it turned out, the cost and availability constraints associated with Nexpert *Object* ruled it out from further consideration.

ART

ART is an expert system development tool marketed by Inference Corporation. It is a full programming environment providing reasoning and database access via an inference engine and an object-oriented knowledge representation mechanism.

ART was considered as the reasoning component of PVEX in the early stage of development. Domain knowledge such as rules and heuristics were implemented using the ART language. The advantages of using ART as the reasoning facility are: (1) ART language is very powerful for organizing declarative knowledge into a knowledge base, and for organizing knowledge into rules. (2) ART includes an interactive development environment (the ART Studio) that offers monitoring and debugging aids for application development. (3) It provides the facility (ARTIST) for building complete a user interface including menus and graphical displays.

However, ART maps the language into Lisp code and integrates it into the Lisp environment, and Lisp is not available at Production Engineering Division (PED). Also, ART rule bases and knowledge bases are difficult to modify/maintain by personnel without any previous experience in logic programming, and this is a burden to the user. For example, rules must be written in a special format to take advantage of backward chaining, and then they are not useful for forward chaining. For these reasons, ART was not considered a viable tool for PVEX.

CLIPS

The C Language Production System (CLIPS) is an expert system shell developed by the NASA/Johnson Space Center. CLIPS was designed specifically to provide easy portability, compatibility and lower cost. The primary representation methodology is a forward chaining rule language based on the RETE algorithm. Advantages to this package are: (1) CLIPS was free of cost to PED. (2) The knowledge-base structure contains all of the heuristical rules in one database, thus making the database very maintainable. (3) An inference engine controls the overall execution. (4) CLIPS code is transportable to any machine with a standard C compiler.

However, CLIPS is an inflexible and fairly limited language. Although it provides an inference engine, only forward chaining is supported. It does not provide an object-oriented knowledge representation system, and efforts to create one became quickly cumbersome. Programs in CLIPS are complicated and difficult to make user friendly. In addition, it was determined that any necessary reasoning could be accomplished via a hypertext-driven system, and that a true inference engine, while desirable, was not mandatory. Since an objective of PVEX is to provide a powerful system while also providing a very friendly environment, CLIPS was also not considered as a viable tool.

KNOWLEDGEPRO

Knowledge Pro is a PC-based expert system shell was designed to provide users with a programming environment free of complex syntax that is easy to learn and use. Its main feature is the ability to incorporate hypertext documents. In such a document, any area of text throughout the document can be linked to additional levels of information that clarify the concept. Using such an expert shell can provide an on-line help facility for viewing different levels of help at anytime. Giving the user the capability to decide what to read next depending on interest and need is referred to as "non-linear" text. Advantages to this system are: (1) inference capability/rules; (2) forward and backward chaining; (3) automatic linking of text / hypertext; (4) help facility; (5) windowing system; and (6) menu generator.

Unfortunately, this application program was found to be incompatible with the Sun environment. Other disadvantages are listed as poor user interface, length of code, block structure limits flexibility, and slow database manipulation. Thus, KnowledgePro was also ruled out as a viable tool.

KNOWLEDGE MANAGEMENT SYSTEM (KMS)

Knowledge Management System (KMS) is a distributed hypermedia-based knowledge management system developed by Scribe Systems, Inc. The major components of KMS include (A) the facility to build up frames and links between frames which contain the knowledge associated with the domain in the actual links (B) the linear document formatting program facilitates moving through the hierarchy (tree) structure of frames; and (C) the Action Language which meets the programming needs of end users. "A frame is a screen-sized 'worksheet.' Like a sheet of paper, it may contain any arrangement of text, graphics, and images."

KMS is very attractive because its frames are treated as a document and the level of effort to maintain the links is analogous to the documentation maintenance process. Documents are organized as a hierarchy and hence lend structure to the organization of the knowledge and its links. This also facilitates the browsing process when working with a KMS document in the

interactive mode. KMS provides a rich hypermedia-based knowledge representation with template sharing and a context-sensitive cross referencing capability. It is also compatible with UNIX and the Sun workstation.

Since the producibility heuristics acquired from the PED domain expert can be readily organized into a hierarchy which is strongly related to a tree structure, KMS was the logical choice as the primary reasoning facility in PVEX. Each KMS frame represents a decision node in the heuristic tree, and the path between a node and its subtree is joined by a link. Another advantage of using KMS is that there is no need to build an independent user interface, because the user interface is built when the decision tree is constructed. KMS provides a very user friendly environment to create, modify, or delete objects in a frame as well as frames in a frame set. By incorporating KMS Action Language, the reasoning facility may easily interface with databases via UNIX scripts.

KMS also was utilized as the explanation and help facility because its hypermedia/hyper-graphics system is well-suited to implementing non-linear on-line documents. The reasoning and explanation facility thus are closely coupled without requiring much effort to interface them. Thus, KMS appeared to be the most suitable of the several application programs for use in developing the P/VEX model.

DATABASE TOOLS

The necessity to access several databases from CADDS and/or KMS required that the choice of database tools be considered. Only two choices were available, AWK and INGRES. Both are compatible with UNIX based systems.

The data with which PVEX is dealing is materials and processes information. This information is primarily static with the exception of costs, thus making a row/column database structure highly useful.

AWK was originally designed and implemented as a part of a UNIX tools experiment. It is a simple programming language that handles simple mechanical data manipulation very efficiently. An AWK program usually is a sequence of patterns and actions indicating what to look for in the input data and what to do when it is found. AWK searches a set of files for records matched by patterns. When a match is found, the corresponding action is performed. AWK expects rows or records containing columns or fields in a simple ASCII format. Maintenance of AWK programs is simple.

On the other hand, INGRES was prohibitive because of expense and license restrictions. AWK was chosen as the database manipulation tool for its ease of use, low cost, and portability.

PVEX FUNCTIONALITY

As stated in the Introduction, the host of the system is a Sun Microsystems workstation, operating under the UNIX operating system. The chosen expert system shell, KMS, operates through script files in an interactive manner. This allows access to the CADDS applications program from within KMS, so that a part and its specifications may be addressed directly from KMS. Context-sensitive help facilities assist the user in both use of the system and in capturing the reasoning of the user during a work session with PVEX. The system, as defined under the operating environment, is self-documenting and is fully transportable to other hosts operating under the UNIX operating system (see Figure 1).

The heuristics that have been incorporated into PVEX are written in individual frames, rather than in the form of a rule base. In so far as the user is concerned, there is no difference in performance. Knowledge is stored into four major databases; (1) the materials database; (2) the processes database; (3) the knowledge database; and (4) the comparator database. These databases, together with the user's responses or requests, are used in making recommendations to the user for materials and process selection. PVEX does not itself select a preferred material or process; that is the user's responsibility.
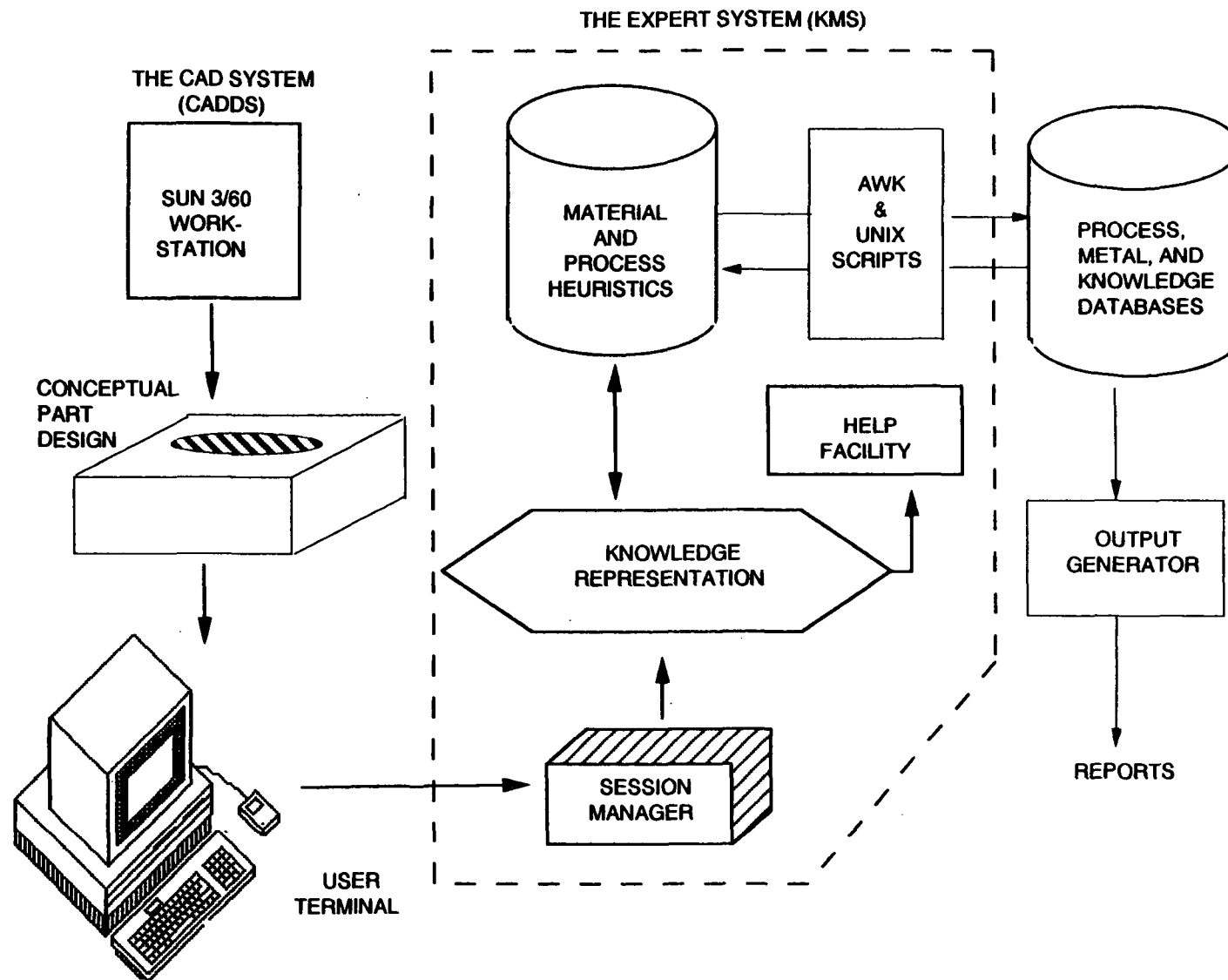
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THE EXPERT SYSTEM (KMS)

THE CAD SYSTEM
(CADDS)

SUN 3/60
WORK-
STATION

CONCEPTUAL
PART
DESIGN

USER
TERMINAL

MATERIAL
AND
PROCESS
HEURISTICS

AWK
&
UNIX
SCRIPTS

PROCESS,
METAL, AND
KNOWLEDGE
DATABASES

HELP
FACILITY

KNOWLEDGE
REPRESENTATION

OUTPUT
GENERATOR

SESSION
MANAGER

REPORTS

Figure 1. Producibility/Value Engineering Expert System Overview

SYSTEM FUNCTION

The user's objective in using the system is to generate a feasible recommendation for the material and process to use for a specific part in a weapon system. First, the system gathers general information pertaining to the user through a script file. The information includes user's name, date, part name, system name, drawing name, and drawing number.

When this information is provided by the user, PVEX prompts for answers which are used to determine the path the user will follow while processing. The answers are stored in temporary files. The system then asks the user if an initial material is known. If there is a known initial material, a script file is invoked to retrieve the initial material. However, if the user does not know an initial material or would like to verify a predetermined material, the system begins to traverse the material selection tree. Once flow begins in the material selection tree, PVEX asks a series of questions based on heuristical knowledge in friendly menu driven screens. Answers to these heuristical questions are stored in a data file. This data file contains vital facts based on the responses to the heuristical questions concerning materials. This file acts as a facts file to show the user WHY particular materials were chosen. Control is performed through script files called from within KMS which interface with the UNIX working environment. Continuing with the system, a script is invoked to open a window and to search the material database and to list feasible materials. Control of the order of material operational database manipulation programs (AWK) is captured in this script. If no materials were chosen, a message will appear to inform the user. Next, the user is prompted for further information about each material. If the selection is no, the system will return control back into KMS. However, if the selection is yes to requiring more information pertinent to material selection, control is passed to a awk file. This awk file returns a list of material properties for each selected material. This list is displayed on the screen or is sent to a printer. Once the process is finished, control of the system returns to KMS.

Once control is returned to KMS, the user can either A) continue with process selection, B) re-evaluate material selection, or C) exit from the system. Depending upon the selection, the user will either flow down the process hierarchical tree or have further options, which include generating a report.

The process hierarchical tree flow works in much the same manner as the material tree flow. The process tree flow asks the user heuristical questions based on processes and stores the associated data in a file. This file will act as a facts file to show the user WHY particular processes were chosen.

DATABASE IMPLEMENTATION

Database generation was necessary to provide the system with knowledge about materials and processes so that it reasons effectively when generating producibility and value engineering alternatives. A survey of existing databases concluded that there are no readily available databases which provide sufficient detail and proper format to meet PED specifications for an internal database. The four databases were then generated through efforts of PED domain experts and UAH research efforts. The comparator and knowledge databases are strictly knowledge databases whereas the process and metals databases are strictly numerical databases. The comparator database is a list of processes matched with known materials to which these processes apply. However, the knowledge database is a list of processes and particular features that are associated with the process. Not all features can be utilized by a particular process.

HELP FACILITY

An on-line help facility is integrated into PVEX through KMS frame links. It makes finding information easy and quickly. The help facility consists of 280 frames which contain in-depth definitions and graphic illustrations of typical material and process selection terms. Information included in this facility was gathered from experienced engineers and from well-established up-to-date handbooks of metals and processes.

The help facility was designed so that it could be used as a stand-alone utility, as well as an aid to the engineer who is operating the PVEX system. It can be accessed as a stand-alone utility through the PVEX initial frame. From this point, control is maintained through submenus and return commands. It is structured so the user can go back and forth from menu to term and back to menu to make several selections in one run. An example of the structured help is shown in Figure 2. In addition to being a stand-alone utility, the help facility can also be accessed from the PVEX heuristic frames. Control is passed to the help frame and then returns the user to the point in the system where he needed the help. The user can then continue with the expert system. An example of stand-alone operation is given in Figure 3.

GRAPHICAL INTERFACE

To enhance the user interface, the expert system provides on-screen pictures, or graphics, to provide a more detailed description of the current question or statement. Some of these graphics were simply drawn on the Sun workstation using CADDS and saved as a Sun format "rasterfile" using the screendump command. These images are required to be 1-bit deep (black & white), as opposed to 8-bit (color) rasterfiles. Other, more complex images, that appeared in books and other printed publications, were obtained using a scanner connected to computers other than the Sun workstations.

The scanned images were imported into KMS in a couple of days which in turn would have required weeks if drawn directly in KMS or CADDS. Advantages of this capability is that PED can view current images and add more images to the PVEX system, as desired, while running on any UNIX machine that is able to view rasterfiles.
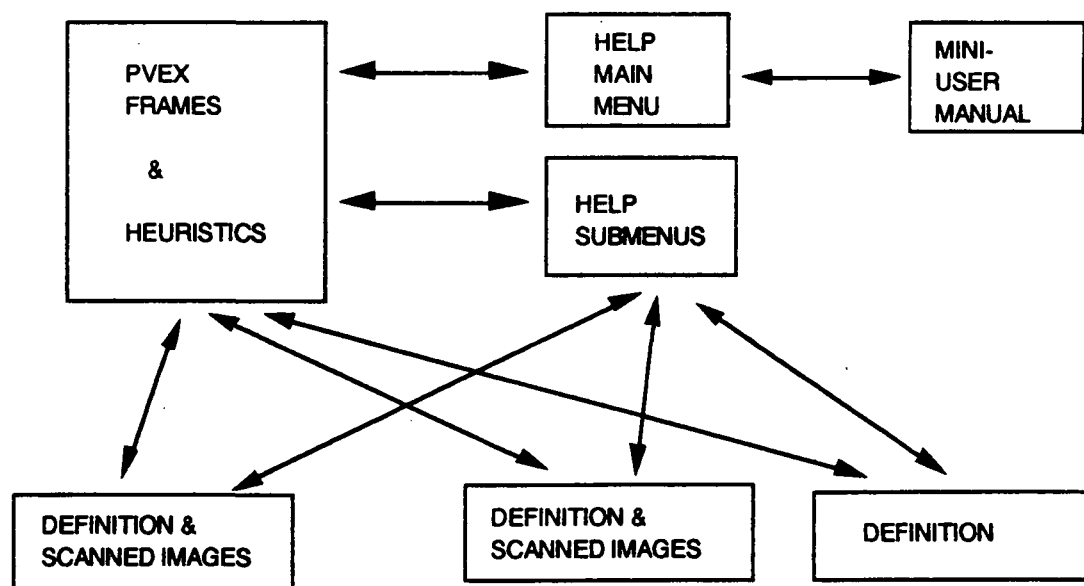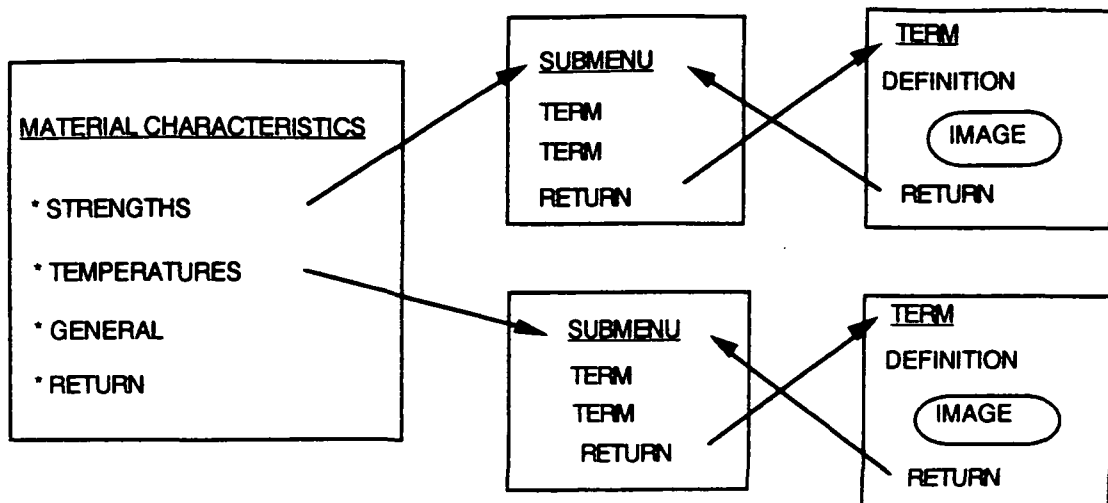

Figure 2.System Building Blocks of the Help Facility

** NOTICE THAT THE RETURN STATEMENT AT THE BOTTOM LEFT HAND CORNER
OF THE FRAMES RETURNS CONTROL TO THE LAST FRAME THAT WAS SELECTED.

Figure 3. Stand-Alone Operation of The Help Facility

CONCLUSIONS

As the foregoing discussion indicates, PVEX is an extremely powerful, flexible and easy-to-use design and design audit system. It can be up-dated "on the fly" and is readily transportable to other UNIX based systems. The coding is self-documenting, and its ability to capture knowledge from the user, databases and the CADDS system provides an ability heretofore not realizable. While KMS itself does not use inferencing rules in the traditional sense of conventional expert systems applications programs, its frame structure accomplished the same purpose and also provides the necessary linking to other frames or utilities. Since the system also supports the display of scanned images of parts and assemblies not already in the CADDS file format, the evaluation capability of PVEX extends beyond the capabilities of CADDS.

The capability provided by PVEX is necessary for achieving concurrent or simultaneous engineering; e.g., the design of the product and the process at the same time and in an interactive mode. As is evident from the structure of PVEX, the material is selected first, followed by the process selection. These steps can be iterated as many times as necessary in order to obtain an optimal matching between material and process.

The structure of PVEX can be easily extended. As the system is structured, composite and non-metallic materials can be incorporated into PVEX with very little modification. The basic form of PVEX can be extended to other material and process selection cases. While there are a number of refinements that could be added to PVEX, it is in its present form a useful design and production tool ready for use by producibility engineers in designing new products or in the re-design or evaluation of existing products.

ACKNOWLEDGEMENTS

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REFERENCES

1. Aho, A., et. al., *The AWK Programming Language*, Addison-Wesley Publishing Company, Reading, Massachusetts, 1988.
2. Aho, A., et. al., "AWK - A Pattern Scanning and Processing Language," *Software Practice and Experience*, July 1978.
3. Akscyn, R., et. al., "KMS: A Distributed Hypermedia System For Managing Knowledge In Organizations," *Communications of the ACM*, July 1988, Vol. 31, Number 7.
4. Conklin, J., "A Survey of Hypertext," *IEEE Computer*, Sept. 1987.
5. Kerrighan, B., and Rob Pike, *The UNIX Programming Environment*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1984.